Monitoring Basal Area Coverage of Eelgrass in Port Townsend Bay

James G. Norris
Marine Resources Consultants

Tedd Hutley
Port Townsend Marine Science Center

Introduction

Seagrass meadows are a critical component of marine ecosystems throughout the world (Phillips and McRoy, 1980; Larkum et al., 1989; Simenstad, 1994). Documenting changes in seagrass distributions can be used to assess nearshore ecosystem health (Dennison et al., 1993; Dobson et al., 1995). Seagrass monitoring programs should be cost-effective, statistically valid, and capable of detecting changes over time (Iredale and Ferguson, 1995; Mumford et al., 1995; Lee Long et al., 1996).

In Puget Sound the seagrass *Zostera marina* (commonly referred to as "eelgrass") is ubiquitous along shorelines from the low intertidal zone down to a depth of about 6.6 m below mean lower low water (MLLW) (Phillips, 1972). To protect Puget Sound eelgrass habitat the Washington State Department of Fish and Wildlife (WDFW) has a "no net loss" policy (Fresh, 1994). Any waterfront construction project that may impact eelgrass habitat must first obtain a Hydraulic Project Approval, which may require mitigation (Fresh, 1994; Thom, 1994). The Washington Department of Natural Resources monitors eelgrass habitat in the low intertidal zone by direct beach observations and aerial surveys (Mumford, 1994). There is no systematic monitoring of Puget Sound eelgrass below MLLW.

In July 1994, the Port Townsend Marine Science Center added semi-annual (summer and winter) underwater video (UV) eelgrass surveys to its community-based environmental monitoring program (Norris and D'Amore, 1996; Norris and Hutley, 1997). This comprehensive monitoring program integrates scientific data collection with environmental education and includes beach observations, conventional water quality monitoring, weather observations, beach seine observations, and annual demersal fish abundance surveys. The objective of the UV eelgrass surveys is to map and estimate basal area coverage of eelgrass along a one mile section of the Port Townsend waterfront. We define "basal area coverage" to be the number of square meters of the seabed that is occupied by eelgrass. Field maps showing the approximate eelgrass distribution have been produced for each survey, but prior to this study no basal area coverage estimates had been prepared.

Norris et al. (1997) described a technique for estimating basal area coverage from a single UV survey. Their technique collects georeferenced observations of the seabed by integrating UV images with continuously updated (every 2 sec) global positioning system (GPS) data. Images are collected along straight line transects conducted in a grid pattern throughout a study area, and the first and last seagrass observations on each transect are used to delineate the perimeter of the occupied seagrass habitat. The resulting irregular polygon is defined to be the sample region and its area in m^2 is computed using analytic geometry. To account for seagrass patchiness within the sample region, each UV transect is further analyzed to compute its length within the sample region and the length during which seagrass was visible. This sampling scheme is identical to cluster sampling with unequal cluster sizes (each transect is considered to be a cluster of samples) from which a point estimate and approximate 95% confidence interval for seagrass basal area can be computed. When applying this technique in a monitoring context (i.e., multiple surveys over time), Norris et al. (1997) recommend defining a "global" sampling region from the first and last seagrass observations from all surveys.

The study reported here has three goals. First, we test the applicability of the Norris et al. (1997) technique in a monitoring context, focusing on the problem of defining a global sampling region and its effect on sample estimates. Second, we estimate the four-year trend in eelgrass basal area coverage in one location along the Port Townsend waterfront. Third, we examine differences in basal area coverage between summer and winter surveys.

Methods

Study Site

Each four-day UV survey collected data from a one-mile section of waterfront between Point Hudson and the Port Townsend Boat Haven. Figure 1 shows the field map of eelgrass distribution prepared from the September 1997 survey. We computed basal area coverage estimates only for the section nearest the Port Townsend Boat Haven. This site covers approximately 190 m of shoreline and includes about 17 acres between MLLW and the 10-m depth contour. We selected this section because it is the largest continuous eelgrass bed in the study area and the Port of Port Townsend is considering expanding the Port Townsend Boat Haven.

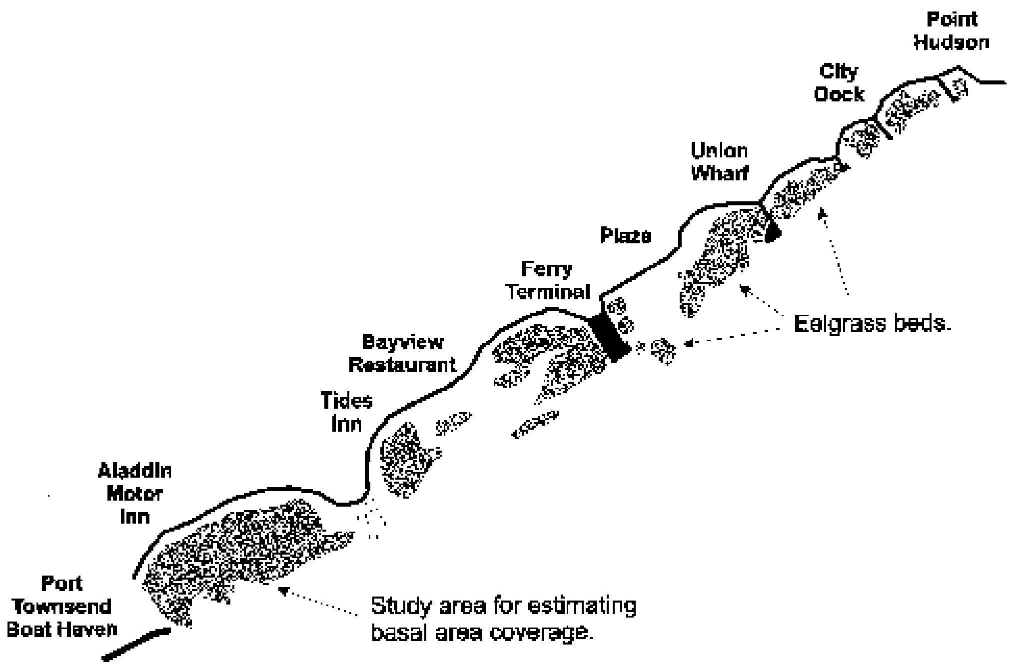

Figure 1. Eelgrass distribution along a one-mile section of the Port Townsend waterfront prepared from the real-time mapping data collected during the September '97 survey. All basal area coverage estimates were determined for the eelgrass bed just northeast of the Port Townsend Boat Haven.

Underwater Videographic Mapping System Overview

The mapping system was composed of two components—a real-time mapping system and an underwater videographic system (Figure 2). The real-time mapping system created preliminary thematic maps during the data collection process in the field. These maps were helpful for adjusting field sampling plans. Data collected by the underwater videographic system were post-processed and analyzed in the laboratory to estimate basal area coverage.

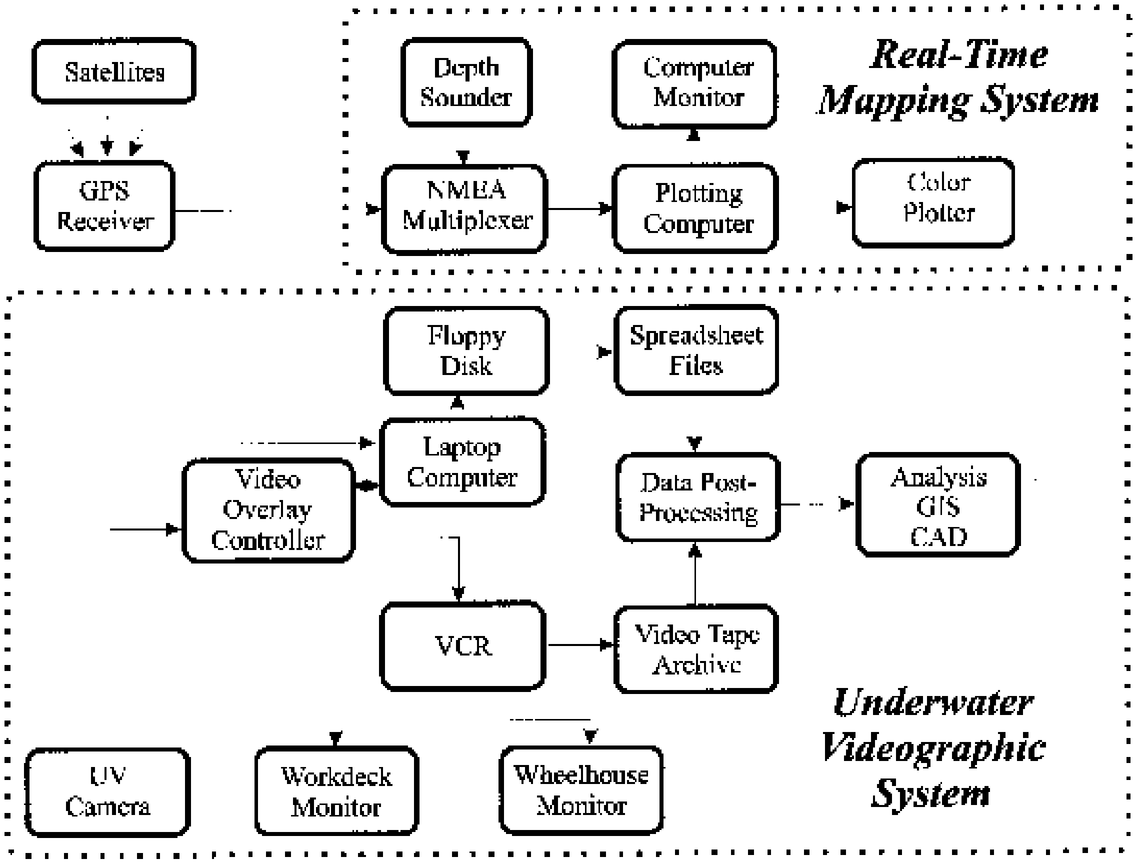

Figure 2. Schematic diagram of the underwater videographic mapping system used in this study.

Survey Equipment

The system was deployed aboard the 11-m commercial fishing/research vessel *Brendan D II*. For six of the eight surveys, position data (latitude and longitude) were acquired by differential GPS (DGPS) from the United States Coast Guard public DGPS network. DGPS was not available for the first two surveys. The GPS antenna was located at the tip of the cargo boom used to deploy the camera. Underwater video images were obtained using an underwater camera mounted in a "down-looking" orientation on a heavy towfish. A 250-watt underwater light provided illumination. The towfish was deployed directly off the stern of the vessel using the cargo boom and boom winch. The heavy weight of the towfish helped keep the camera positioned directly beneath the DGPS antenna. A laptop computer equipped with a video overlay controller and data logger software integrated DGPS data (date, time, latitude, longitude) and the video signal. DGPS data (updated every 2 sec) and transect identification numbers were stored directly onto the videotape using a four head video cassette recorder (VCR). Date, time and position also were stored on a floppy disk at two-second intervals. Television monitors located in both the pilothouse and the work deck assisted the helmsman and winch operator control the speed and vertical position of the towfish.

Field Sampling Procedures

We used a systematic sampling plan composed of straight line transects both parallel and perpendicular to the shoreline. At the start of each transect, the vessel was backed close to the shoreline or dock and the camera was lowered to just above the bottom. Visual references are noted and the VCR and data logger were started. As the vessel moved along the transect the winch operator raised and lowered the camera towfish to follow the seabed contour. The field of view changed with the height above the bottom, but averaged about one square meter. The vessel speed was held as constant as possible (about one m/sec) so that time could be used as a proxy for distance in some analyses. A tension line from the deck winch was used to help keep the towfish cable in a vertical orientation. At the end of the transect, the VCR was stopped, the camera was retrieved, and the vessel was moved to the next sampling position.

Real-Time Mapping

The real-time mapping system input DGPS position data directly into a spreadsheet program. Position data were added to three data series that were plotted on a chart embedded in the spreadsheet, each series plotted using a different pattern. Virtual toggles or buttons, also embedded in the spreadsheet, controlled which data series were updated with each position update (Figure 3). The first series consisted of only one point—the current longitude and latitude. Each of the remaining two plotting series consisted of longitude and latitude coordinates for the vessel track line when eelgrass was present or absent. These series were updated only if the “tracking” or “eelgrass” toggles were turned on, respectively. The “eelgrass absent” series was plotted as a thin black line, whereas the “eelgrass present” series was plotted as a thick green line. As the vessel moved along the track line, an observer watched the TV monitor and clicked the eelgrass toggle on or off each time eelgrass appeared or disappeared. The result was a real-time plot of the area sampled and where eelgrass was observed.

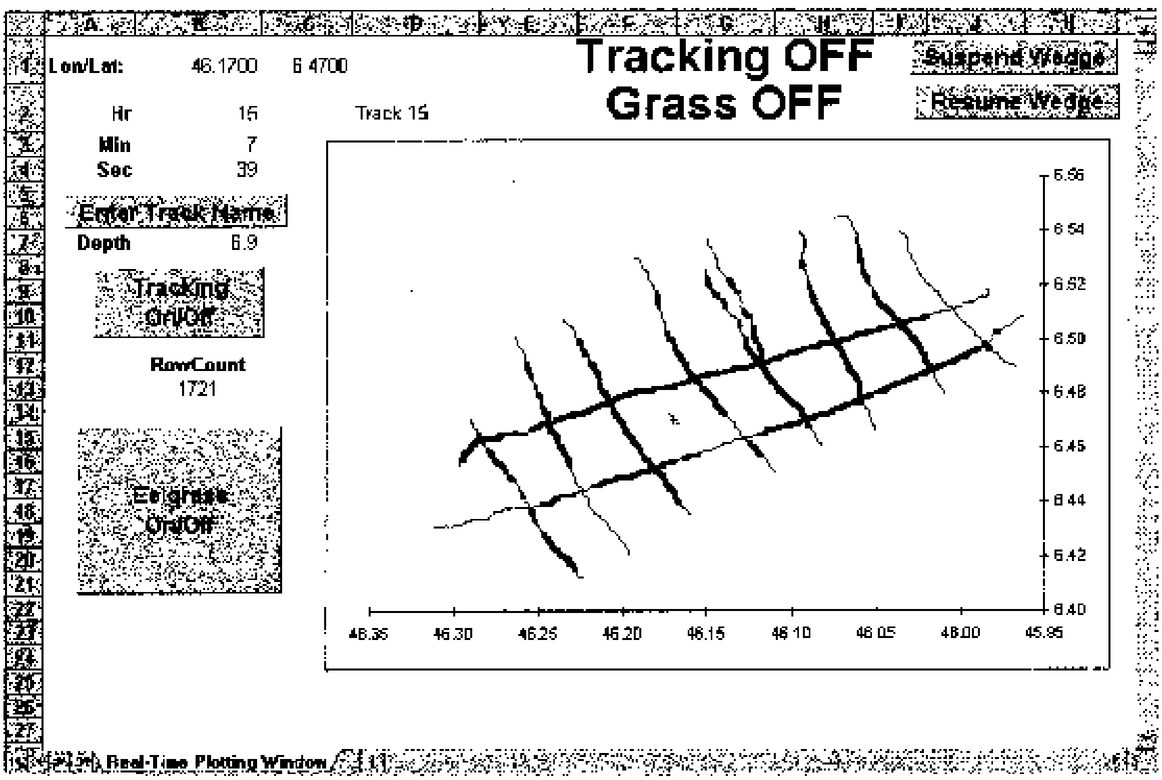

Figure 3. Sample computer screen window for the real-time mapping system. The square marker with cross-hair indicates the current vessel position. When the “Tracking On/Off” button is clicked by the observer to note that the camera is viewing the seabed, a thin line is plotted as the vessel moves along the transect. When the “Eelgrass On/Off” button is clicked by the observer to note the presence of eelgrass on the video monitor, the plot line changes to a thicker line (plotted in green on a color monitor).

Underwater Video Data Post-Processing

Data stored on floppy disks were downloaded and organized into spreadsheet files with separate columns for date, time, and position data. A blank column was created for "eelgrass code." Videotapes were reviewed in the laboratory to assign one of five eelgrass codes to each position record: absent (code = 0), low density (code = 1), medium density (code = 2), high density (code = 3), and undetermined (code = 9). The low, medium, and high-density classifications were determined by the subjective judgment of the videotape reviewer.

To define a global perimeter, we first plotted perimeters for each survey (Figure 4). Perimeters for the six surveys using DGPS were nearly identical, and a global perimeter was defined that encompassed all survey perimeters. For statistical analysis, this global perimeter delineated the sample region for these six surveys. The two early surveys that did not use DGPS had quite different perimeters. For these two surveys, each individual survey perimeter was used to define its sample region.

Statistical Analysis

For each survey, individual transects were analyzed using a proprietary software program. The perimeter defining the sample region was plotted along with each transect. A transect was eliminated from basal area coverage analysis if it did not follow a substantially straight path, or did not pass continuously through the study region. (E.g., some transects were aborted midway through the sample region due to technical problems during data collection; other transects were very close and parallel to the eelgrass bed perimeter and meandered in and out of the sample region).

A few transects from the six surveys using DGPS started within, but very close to, the global perimeter defining the nearshore edge of the sample region. This situation was caused by the two to five meter accuracy limits of DGPS and the fact that some transects running perpendicular to the shoreline started less than 5 m inshore from the nearshore edge of the eelgrass bed. For these transects, the analysis program added to the total length and eelgrass absent component of the transect the distance between the start of the transect and the global perimeter.

For each accepted transect, the program computed the length of the transect passing through the sample region and the lengths associated with each eelgrass code. Once all transects for a survey were analyzed, the following procedures were used to compute basal area coverage estimates and confidence intervals.

Let n be the number of random samples (transects) through a sample region and for the i^{th} transect let m_i = length (meters) passing through the sample region and a_i = length (meters) with seagrass. The proportion of the study region having eelgrass was estimated by Cochran (1977, eq. 3.31).

$$\hat{p} = \frac{\sum a_i}{\sum m_i} \tag{1}$$

Cochran (1977) notes that this estimate is "slightly biased, although the bias is seldom likely to be of practical importance." The estimated variance of p is given by Cochran (1977, eq. 3.34).

$$\operatorname{var}(\hat{p}) = \frac{\sum a_i^2 - 2p\sum a_i m_i + p^2 \sum m_i^2}{n(n-1)\overline{m}^2} \tag{2}$$

where $\overline{m}$ is the mean number of elements in a sample unit (= $\Sigma\, m_i / n$). If the transects are of equal length (i.e., $m_i = m$ for all i), the estimates of p and var(p) are just the sample mean and sample variance of the p_i (= a_i/m). The point estimate and approximate 95% confidence interval for the total number of square meters covered by seagrass (A) is given by:

$$\hat{A} = N(\hat{p} \pm 2\hat{\sigma}_p) \quad (3)$$

where $\hat{\sigma}_p$ is the estimated standard deviation of *p*.

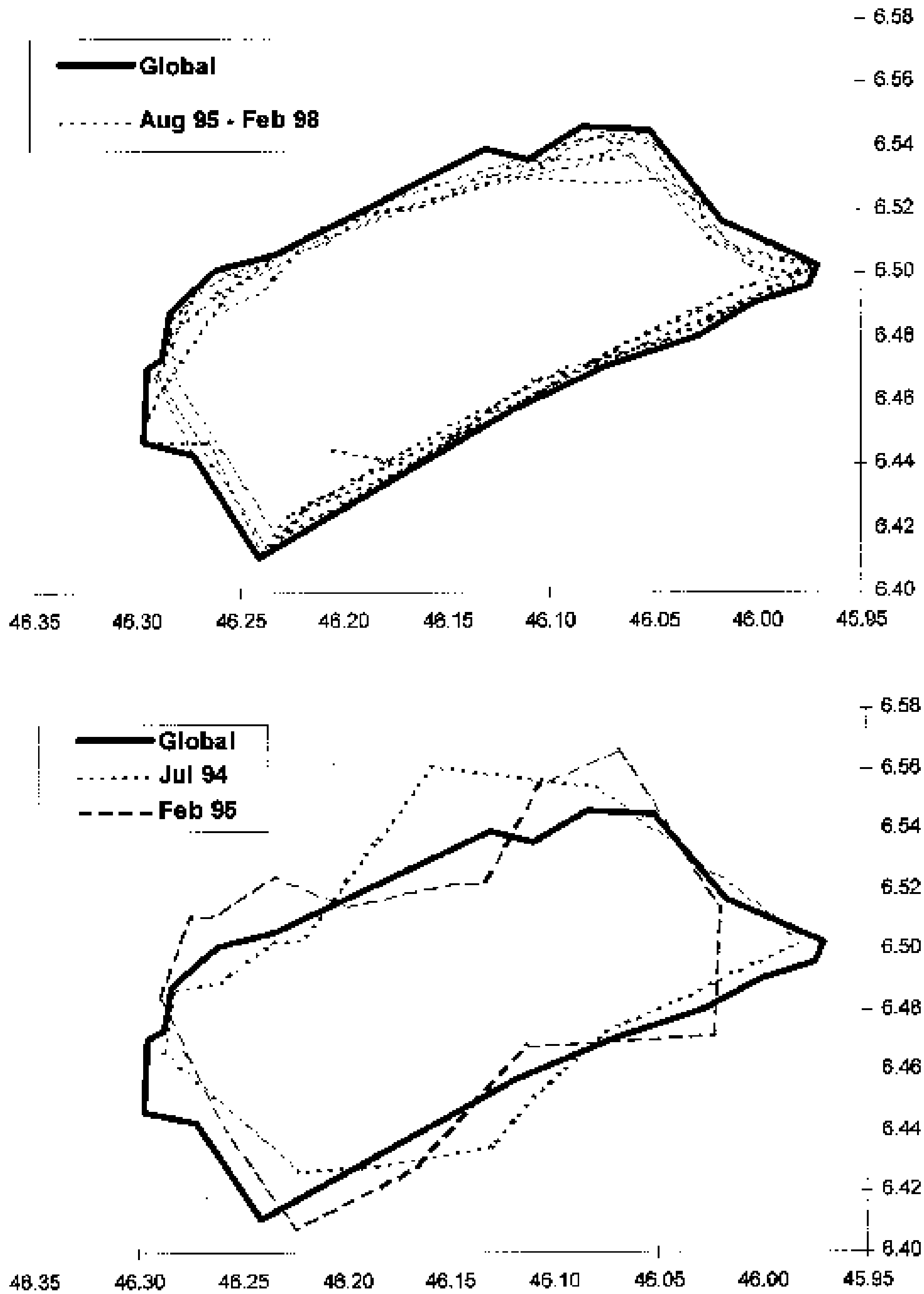

Figure 4. Upper panel (previous page) shows the eelgrass bed perimeters for the six surveys using differential GPS and the “global” perimeter (heaviest black line) used for estimating basal area coverage. Lower panel shows the eelgrass bed perimeters for the two surveys that did not use differential GPS (global perimeter also shown for reference).

Results

A total of 110 transects were included in the analysis (Table 1). The histogram of eelgrass fractions from all transects in all years showed a normal distribution with mean = 0.69 and standard deviation = 0.13 (Figure 5). These values are quite similar to those reported in Norris et al. (1997) for 32 UV transects taken fro m a different Puget Sound eelgrass bed (mean = 0.76; standard deviation = 0.124).

Table 1. Data summary for eight underwater videographic eelgrass surveys in Port Townsend Bay (n = number of transects in the sample region used to estimate basal area coverage). Sample length is the sum of the lengths (in meters) from all n transects passing through the sample region (i.e., Σm_i). Eelgrass lengths for low, medium, and high densities are the sums of the lengths (in meters) from all n transects that have eelgrass of associated density (i.e., Σa_i)

		Sample Length	Eelgrass Lengths (m)				Estimated Eelgrass Fraction $\hat{p}$			
Survey	n	(m)	Low	Med	High	Total	Low	Med	High	Total
Jul-94	13	2,432	116	483	809	1,409	0.05	0.20	0.33	0.58
Feb-95	18	3,453	579	1,021	563	2,164	0.17	0.30	0.16	0.63
Aug-95	14	2,415	196	451	1,004	1,652	0.08	0.19	0.42	0.68
Feb-96	10	1,728	97	380	662	1,138	0.06	0.22	0.38	0.66
Jul-96	14	2,078	92	315	1,057	1,464	0.04	0.15	0.51	0.70
Mar-97	14	2,400	140	1,209	456	1,806	0.06	0.50	0.19	0.75
Sep-97	9	1,856	83	233	1,047	1,363	0.04	0.13	0.56	0.73
Feb-98	18	3,332	175	418	1,895	2,489	0.05	0.13	0.57	0.75

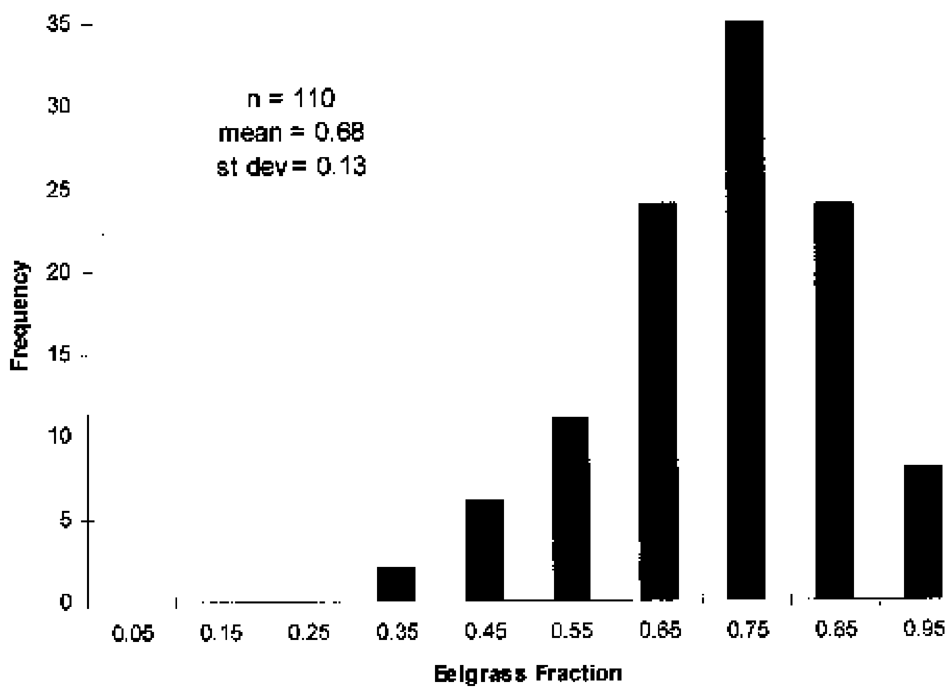

Figure 5. Histogram of total eelgrass fractions collected from 110 UV transects during eight surveys in Port Townsend Bay.

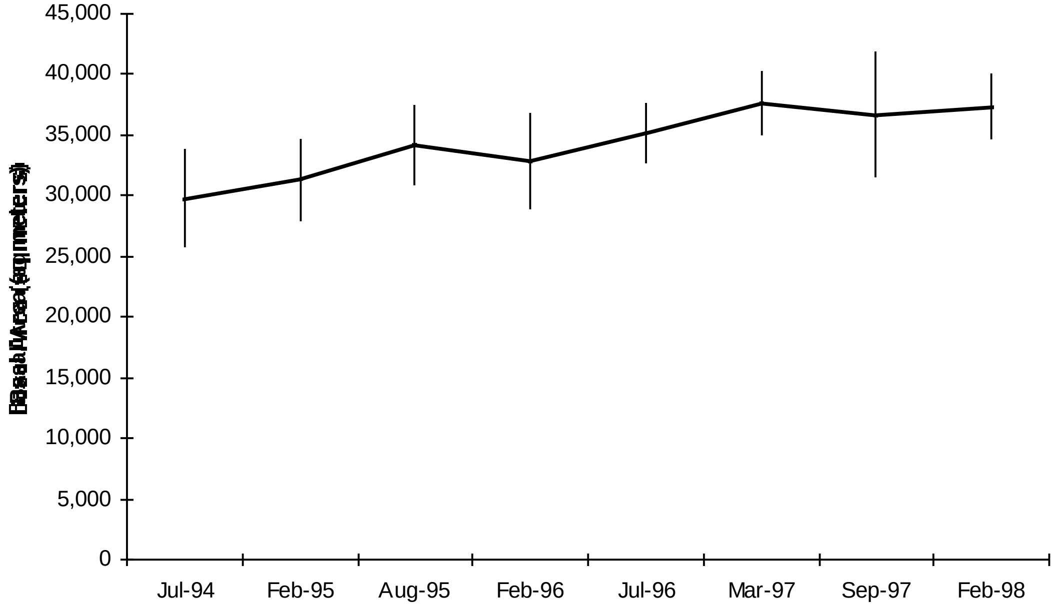

Figure 6. Basal area coverage estimates (with 95% confidence limits) for total eelgrass presence in the sample region.

Overall basal area coverage showed an increasing trend over the four-year period (Table 2; Figure 6). The point estimates for the first (July 1994) and last (February 1998) surveys were 29,808 m^2 and 37,310 m^2, respectively. This is an increase of 7,502 m^2 (25%). The confidence intervals ranged from 7% to 14% around the point estimates.

There were no significant changes in overall basal area coverage between the winter and summer surveys. Also, the low, medium, and high-density eelgrass estimates showed no consistent trends based on our subjective characterization (Table 2).

Discussion

The primary technical difficulty in applying the Norris et al. (1997) method in a monitoring context was that some transects had to be eliminated or adjusted to meet the statistical analysis criteria. This difficulty can be removed by defining the global perimeter of the sample region before field sampling and having the global perimeter plotted on the real-time mapping screen during field sampling. This will ensure that all transects pass completely and continuously through the sample region.

The confidence intervals around the point estimates were not as narrow as we would have liked. As expected, the confidence limits were generally narrower when sample sizes (i.e., number of transects) were larger. To estimate how many transects would be needed to reduce the 95% confidence intervals to within 5% of the point estimate (i.e., coefficient of variation = 0.025), we can assume all transects have the same length and use the standard deviation of the eelgrass fractions from all 110 transects ($\hat{\sigma}_p$) as follows:

$$\hat{n} = \frac{\hat{\sigma}_p^{\,2}}{(0.025)^2}$$

Table 2. Basal area coverage estimates (m^2) with upper and lower 95% confidence bounds for low, medium, and high density eelgrass and total eelgrass presence from eight underwater videographic surveys in Port Townsend Bay.

Survey Date	Eelgrass Density	Lower Bound	Point Estimate	Upper Bound
Jul-94	low	1,491	2,458	3,426
	med	7,455	10,229	13,003
	high	13,209	17,121	21,032
	total	25,733	29,808	33,884
Feb-95	low	6,100	8,390	10,681
	med	12,297	14,791	17,285
	high	4,756	8,159	11,562
	total	27,982	31,341	34,700
Aug-95	low	2,272	4,053	5,835
	med	6,923	9,334	11,744
	high	15,352	20,776	26,200
	total	30,827	34,163	37,499
Feb-96	low	1,786	2,798	3,810
	med	8,801	10,974	13,148
	high	15,180	19,124	23,069
	total	28,926	32,896	36,866
Jul-96	low	1,387	2,216	3,046
	med	5,589	7,581	9,573
	high	21,521	25,395	29,270
	total	32,711	35,193	37,675
Mar-97	low	2,129	2,916	3,704
	med	20,135	25,177	30,220
	high	3,662	9,496	15,329
	total	34,937	37,590	40,243
Sep-97	low	743	2,227	3,712
	med	3,620	6,272	8,923
	high	21,159	28,170	35,181
	total	31,470	36,669	41,868
Feb-98	low	1,976	2,629	3,282
	med	4,138	6,267	8,397
	high	23,711	28,414	33,116
	total	34,616	37,310	40,005

Substituting $\hat{\sigma}_p$ = 0.13 (from Figure 5) gives an estimated sample size of 27 transects. The similarity in eelgrass fraction standard deviations (0.13 vs. 0.12) between transects from this study and that reported in Norris et al. (1997) suggests that a good rule of thumb is that 25 to 30 UV transects are required through a typical Puget Sound eelgrass bed in order to estimate basal area coverage within 5%. It is important to note that the required sample size is independent of the size of the bed. The critical characteristic is how patchily the eelgrass is distributed within the bed perimeter.

Our finding that basal area coverage did not change significantly between winter and summer suggests that the current WDFW policy requiring eelgrass surveys to be conducted only during the summer may be relaxed, depending on the purpose of the survey. If the perimeter of an eelgrass bed and associated basal area coverage are the only parameters of interest, our results suggest that surveys conducted at any time of year will provide the same information. For the Port Townsend Marine Science Center monitoring program we recommend eliminating the winter survey each year and adding two other sites to the summer surveys—-near the mouth of Chimacum Creek and near known herring spawning areas inside Kilisut Harbor.

The fact that we observed a 25% increase in basal area coverage over the four year period also has implications for the WDFW "no net loss" policy. In absolute terms, the observed increase was about 7,500 m^2. This is a significant amount of eelgrass that could easily represent the amount of eelgrass impacted by a nearby construction project. From a policy application perspective, the critical question is: "During what two time periods does a 'no net loss' policy apply?" For example, if the policy for our study region begins in July 1994 (the date of our first survey), the eelgrass bed existing in February 1998 could be reduced by 7,500 m^2 and still satisfy the policy. In more general terms, the question is: Should a construction project that will destroy some eelgrass habitat be allowed to proceed, if it is known that the eelgrass bed in the immediate vicinity has increased naturally by the same or greater amount during the past few years?

In summary, we feel that the UV methodology described here and in Norris et al. (1997) satisfies all of the requirements for an eelgrass monitoring program outlined in the introduction. One day of field sampling effort (25-30 UV transects) at each time period provides statistically valid basal area coverage estimates capable of detecting a 5% change between time periods. This method complements other larger scale remote sensing techniques, such as satellite imagery and aerial photography.

Acknowledgments

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